



Environmental Protection Department
Environmental Restoration Division

Proposed Remedial Action Plan
for the Lawrence Livermore
National Laboratory
Livermore Site,
Livermore, California

October 1991

Lawrence Livermore National Laboratory
University of California Livermore, California 94551

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Summary

This Proposed Remedial Action Plan (PRAP) presents alternatives for remediating contaminants in ground water and unsaturated sediment that originate at the Lawrence Livermore National Laboratory (LLNL) Livermore site. We encourage the public to review and comment on all the remedial alternatives. The preferred alternatives may be modified or another response action may be selected based on new information or public comments.

As described in the Remedial Investigation (RI) report, organic solvents (called volatile organic compounds or VOCs), primarily TCE and PCE; fuel hydrocarbons (FHCs); chromium; lead; and tritium are present at various locations in ground water beneath LLNL in concentrations above State and Federal Drinking Water Standards or Maximum Contaminant Levels (MCLs). FHCs and VOCs occur above the water table in two, and possibly three, small areas in concentrations high enough to potentially produce concentrations in ground water above these standards.

Calculations using EPA methodology of health effects that may result from VOCs if there were no ground water cleanup indicate that, under the most likely circumstances, the maximum increase in cancer risk from a lifetime exposure to water from a downtown Livermore well would be 7 in 10 million (7×10^{-7}). Under assumptions that are very conservative from a health-risk perspective, and which are highly unlikely to occur, the maximum additional cancer risk resulting if no cleanup were to occur would be two in one thousand (2×10^{-3}) if one were to consume water for 70 years from a monitor well drilled 250 ft west of LLNL. Evaluation of the potential for noncarcinogenic health effects from ground water contaminants indicates that no hazard exists under the most likely or health conservative circumstances.

Under the most likely circumstances, the maximum potential additional cancer risk that may exist after cleanup has reduced ground water contaminant concentrations to MCLs is seven in one hundred million (7×10^{-8}). Under the health-conservative scenario, the maximum additional cancer risk is four in one hundred thousand (4×10^{-5}). There is no health hazard from noncarcinogens after the proposed cleanup.

Several approaches to cleaning up the contaminants of concern in ground water and unsaturated sediment were screened and evaluated in the Feasibility Study (FS) report. Viable contaminant extraction and treatment options were assembled into remedial alternatives appropriate for the combinations of contaminants present in different parts of the site.

Three remedial alternatives for cleaning up ground water were developed and evaluated against criteria established by the U.S. Environmental Protection Agency (U.S. EPA). The ground water alternatives are:

1. *Ground water extraction at 18 locations throughout the contaminated areas, including source areas, to stop further contaminant migration and enable the most rapid cleanup.* Ground water would be treated at seven treatment facilities, four of which would use ultraviolet light/oxidation as the primary treatment process. The other three would use air stripping as the primary treatment process. The choice of treatment process is based upon the effectiveness of the process for the particular suite of chemicals in the ground water. The treated water would be recharged to the subsurface or used at the LLNL site. All wells and treatment facilities would be operational in the 1993 to 1994 timeframe. It may take about 50 years to reduce residual contaminant concentrations in ground water to

levels below MCLs. The present-worth cost of this alternative is estimated to be \$103 million. (Present-worth calculations are a way to compare costs of projects that extend over different time periods.)

2. *Ground water extraction at 10 locations within and at the downgradient edges of contamination to stop further migration.* Ground water would be treated at four treatment systems, and the treated water would be returned to the subsurface or used at LLNL. All wells and treatment facilities would be operational in 1993. It may take 90 years or more to reach MCLs with this alternative. The present-worth cost of this alternative is about \$99 million.
3. *Deferred action consisting of monitoring and treatment at the point of use only if water-supply wells contain contaminants from LLNL in concentrations above MCLs.* It could take about 200 years, if ever, for contaminants above MCLs to reach municipal-supply wells in downtown Livermore and an additional 30 years to reduce concentrations to levels below MCLs. The water would be treated by a technology chosen at the time remediation is required. The present-worth cost of this alternative is \$87 million if treatment were actually conducted, and \$12 million if only ground water monitoring were conducted for 100 years.

The remedial alternatives for contaminants in unsaturated sediment are to:

1. *Withdraw vapors by vacuum-induced venting and treat them by catalytic oxidation.* It may take about 10 years to clean up unsaturated sediment using this method. The present-worth cost of this alternative is \$1.1 million.
2. *Allow contaminants to migrate and degrade naturally while monitoring to see if they migrate to the ground water in concentrations above MCLs.* If this occurs, extract and treat the ground water as described for ground water cleanup. It may take 90 years to clean up the contaminants currently in the unsaturated zone under this alternative. The present-worth cost of this alternative is \$0.9 million.

LLNL; the U.S. Department of Energy (DOE); U.S. EPA; the California Environmental Protection Agency, Department of Toxic Substances Control (DTSC) (formerly called the Department of Health Services, Department of Toxic Substances Control); and the California Regional Water Quality Control Board believe that Ground Water Remedial Alternative No. 1 and Unsaturated Zone Remedial Alternative No. 1 will most fully meet the criteria established by EPA to evaluate remedial alternatives. Ground Water Remedial Alternative No. 3 does not fully satisfy the State Applicable or Relevant and Appropriate Requirement (ARAR) for nondegradation of the ground water and does not reduce contaminant mobility until and unless contaminants reach a water-supply well in concentrations higher than MCLs. Ground Water Remedial Alternative No. 1 decreases contaminant mobility more than Alternative No. 2. Although Ground Water Remedial Alternative No. 1 has a somewhat greater present-worth cost than Alternative No. 2, cleanup would be achieved sooner with Alternative No. 1. Unsaturated Zone Remedial Alternative No. 2 does not fully comply with the California nondegradation ARAR and does not reduce contaminant mobility until contaminants reach ground water. Unsaturated zone cleanup could be achieved in 10 years under Alternative No. 1 compared to 90 years for Alternative No. 2.

1. Introduction

This Proposed Remedial Action Plan (PRAP) summarizes remedial alternatives for cleanup of ground water and unsaturated sediment at and near Lawrence Livermore National Laboratory (LLNL), located east of Livermore in the southeastern part of Livermore Valley (Fig. 1). The public is encouraged to comment on all the alternatives discussed in this report and participate in selection of the final remedy, as described in Section 117(a) of the Comprehensive Environmental Response, Liability, and Compensation Act (CERCLA or Superfund) of 1980, as amended. The preferred alternative for cleaning up ground water is ground water extraction at 18 locations and treatment at 7 onsite facilities. The preferred alternative for cleaning up unsaturated sediment is vapor withdrawal and treatment by catalytic oxidation. All the alternatives are described in Section 5 of this report.

This document was prepared by LLNL and the U.S. Department of Energy (DOE) with oversight by the U.S. Environmental Protection Agency (U.S. EPA), the California Regional Water Quality Control Board–San Francisco Bay Region (RWQCB), and the California Environmental Protection Agency, Department of Toxic Substances Control (DTSC) formerly called the Department of Health Services, Department of Toxic Substances Control. LLNL has also worked closely and coordinated with the local water management agency, Alameda County Flood Control and Water Conservation District–Zone 7. LLNL and DOE, together with the other participating agencies, will select a final remedy for the LLNL site only after the public comment period for this report has ended and comments have been reviewed. The preferred alternative may be modified or another response action may be selected based on new information or public comments.

This report summarizes information that can be found in greater detail in the Remedial Investigation (RI) (Thorpe *et al.*, 1990) and the Feasibility Study (FS) (Isherwood *et al.*, 1990) reports, and other documents in the Administrative Record for the LLNL site. LLNL and DOE encourage public review of these documents in order to gain a more comprehensive understanding of the site and the ongoing CERCLA activities. The Administrative Record, which contains all background information upon which the selection of the remedial alternatives will be based, is available at the LLNL Visitors Center, as described in Section 7 of this report. A glossary of technical and regulatory terms is included in Section 8.

2. Site Background

LLNL is a research and development facility owned by DOE and operated by the University of California. LLNL was placed on the U.S. EPA's National Priorities List (NPL) in 1987 on the basis of volatile organic compounds (VOCs) that were discovered by LLNL in ground water offsite in 1983 and the presence of drinking water wells within 3 miles of the site. Currently, about 10,000 people use ground water blended from several downtown Livermore municipal supply wells as their primary drinking water supply, but contaminants from LLNL are about 1.6 miles from these supply wells. Placement on the NPL meant that U.S. EPA began overseeing LLNL's investigation and cleanup activities according to the Federal Superfund Program. This

Figure 1

program provides guidelines and funding for addressing past releases of hazardous contaminants at private and public facilities nationwide. LLNL's cleanup program is wholly funded by DOE.

Between 1987 and 1990, LLNL conducted an RI and FS under the oversight and guidance of DOE and U.S. EPA, along with the RWQCB, DTSC, and the Alameda County Flood Control and Water Conservation District–Zone 7. Figure 2 shows the eight phases of the Superfund process, including the current (PRAP) phase.

Initial releases of hazardous materials occurred in the mid- to late 1940s when the site was the Livermore Naval Air Station (Thorpe *et al.*, 1990). There is also evidence that localized spills, leaking tanks and impoundments, and landfills contributed VOCs, fuel hydrocarbons (FHCs), lead, chromium, and tritium to ground water and unsaturated sediment (i.e., unconsolidated materials above the water table) in the post-Navy era. A screening of all environmental media showed that ground water and unsaturated sediment are the only media that require remediation (Thorpe *et al.*, 1990). The identified compounds that exist in ground water at various locations beneath the site in concentrations above drinking water standards are:

1. The VOCs trichloroethylene (TCE), perchloroethylene (PCE), 1,1-dichloroethylene (1,1-DCE), 1,2-dichloroethylene (1,2-DCE), 1,1-dichloroethane (1,1-DCA), 1,2-dichloroethane (1,2-DCA), carbon tetrachloride, and chloroform.
2. FHCs (leaded gasoline), including benzene and ethylene dibromide.
3. Chromium and lead.
4. Tritium.

The VOCs in ground water beneath LLNL occur in relatively low concentrations that underlie about 85% of the LLNL site, with a total area of about 1.4 square miles (Fig. 3). The calculated total volume of VOCs in ground water is less than 200 gal. The vertical thickness of the ground water VOC plumes varies from about 30 to 100 ft, and VOCs are seldom found below a depth of about 200 ft. TCE and PCE are the predominant VOCs in the study area, and are locally present in concentrations up to 3.2 and 1.1 parts per million (ppm), respectively. However, the higher concentrations are localized and total VOC concentrations exceed 1 ppm in only 8 of 324 LLNL-sampled wells. The distribution of VOCs in ground water exceeding MCLs is shown in Figure 4. The VOCs and chromium (discussed below) in ground water in the vicinity of the Patterson Pass–Vasco Road intersection appear to originate on private property northwest of the LLNL site, as discussed by Iovenitti *et al.* (1991) and Hoffman (1991). This offsite area will be investigated by the potentially responsible party or parties under RWQCB order. If LLNL is found to be the source of chromium in this area, LLNL will incorporate this area into the remedial design.

Chemical data from boreholes drilled at the locations of suspected VOC releases at LLNL indicate that generally low (less than 100 parts per billion [ppb]) residual VOC concentrations are present in unsaturated sediments. Computer modeling indicates that downward movement of VOCs above the water table is not likely to result in ground water VOC concentrations exceeding maximum contaminant levels (MCLs) for drinking water, except at the Building 518 Area in the southeast corner of the site and (Isherwood *et al.*, 1990) in the Gasoline Spill Area in

the southern part of LLNL (Fig. 4). An additional site (Trailer 5475 in the East Taxi Strip Area) may be added to this list when soil investigations are complete.

Figure 2

Figure 3

Figure 4

FHCs occur almost exclusively where a leak of about 17,500 gal of leaded gasoline occurred from a U.S. Navy-era underground fuel tank in the southern part of the site (Figs. 4 and 5). Due to the very slow ground water movement in the area, FHCs in ground water have not migrated more than about 500 ft from the leak point (Thorpe *et al.*, 1990). Within this area, total FHC concentrations in ground water range from 0.001 to 16 parts per million (ppm), and benzene concentrations range from less than 0.0001 to about 4 ppm. Ethylene dibromide was detected in nine Gasoline Spill Area monitor wells above the MCL, in concentrations from 0.0001 to 1.3 ppm. FHCs are not present in ground water beneath a depth of about 150 ft.

Prior to withdrawal of fuel vapor as part of a pilot study in the Gasoline Spill Area, up to 11,000 ppm total FHCs and 4,800 ppm aromatic hydrocarbons were detected in the unsaturated sediments beneath the former fuel tank. Virtually all FHCs in the unsaturated zone are within a horizontal distance of about 50 ft of the leak point.

Metals above MCLs are present in only a few locations. Chromium in ground water exceeds the MCL in 16 wells scattered in the northwest, central, and southwest parts of the study area and near Arroyo Seco (Fig. 6). Recent analyses indicate lead is above the 15 ppb remediation standard (Table 1) in only two wells, both in the Gasoline Spill Area, at a maximum concentration of 38 ppb. Lead has a low potential for migration in both the saturated and unsaturated zones because it binds strongly to sediment (Fish, 1987). This low migration potential, and the very limited extent of lead in LLNL area ground water, indicate that lead at LLNL does not pose a health threat.

Tritium, a radioactive isotope of hydrogen, is used at LLNL for a variety of basic and applied research purposes. It occurs globally in rain and surface waters from cosmic-ray-induced reactions in the atmosphere, nuclear reactor emissions, and as the result of atmospheric nuclear testing performed in the 1950s and 1960s. Tritium is an LLNL and Sandia National Laboratory, Livermore (SNLL) effluent. At LLNL, this effluent results from normal operations, primarily those activities in Building 331.

Recent investigations have indicated that tritium levels in rain and stormwater runoff are elevated on and immediately adjacent to LLNL and SNLL, but the elevated concentrations are localized. Some tritium contamination has occurred at LLNL because of past waste management practices and retention tank leaks. Screening-level calculations presented by Macdonald *et al.* (1990) indicate the known tritium occurrences at LLNL do not pose a risk to human health.

Tritium has been detected in LLNL ground water. Tritium in ground water has historically exceeded the 20,000 picocuries per liter (pCi/L) MCL in only two wells, both in the southeast part of the site. Currently, water from only one of these wells (MW-206) exceeds the tritium MCL. However, the tritium is localized and well defined, and the ground water is not used for drinking water. Furthermore, ground water modeling indicates that by the time the affected ground water moves offsite, the concentrations will be reduced to concentrations below drinking water standards by natural decay (tritium has a 12.3-year half-life). Therefore, no pathway to humans exists for the observed tritium in ground water. According to the U.S EPA, an adult who consumes 2 liters/day of water containing 20,000 pCi/L tritium for 70 years would incur a dose of 4 millirem/year. (See Section 8 for the definition of a millirem.)

Figure 5

Figure 6

Table 1. Remediation standards and State discharge limits for compounds of concern in ground water at the LLNL site.

Constituent	Concentration limit for drinking water ^a			Discharge limit ^b for treated water (ppb)
	Federal MCL (ppb)	California MCL (ppb)	Pre-remediation concentration range at LLNL March 1990–March 1991 (ppb)	
PCE	5	5	<0.1–1,050	4
TCE	5	5	<0.1–4,800	5
1,1-DCE	7	6	<0.5–370	5
cis-1,2-DCE	70	6	<0.5–24	5 (total 1, 2-DCE)
trans-1,2-DCE	100	10	<0.5–1	5 (total 1, 2-DCE)
1,1-DCA	—	5	<0.5–60	5
1,2-DCA	5	0.5	<0.1–190	5
Carbon tetrachloride	5	0.5	<0.1–91	5
Total THM ^c	100 ^c	100 ^c	<0.5–270	5
Benzene	5	1.0	<0.1–4,600	0.7
Ethyl benzene	700	680	<0.2–610	5
Toluene	1,000	—	<0.5–4,200	5
Xylenes (total)	10,000	1,750 ^d	<0.5–3,700	5
Ethylene dibromide	0.05	0.02	<0.1–51	5
Total VOCs	—	—	up to 5,808	5
Chromium ^{+3 e}	50 (total Cr)	50 (total Cr)	<5–150 (total Cr)	50 (total Cr)
Chromium ^{+6 e}	50 (total Cr)	50 (total Cr)	<10–140	11
Lead	15 ^f	50	<2–10	5.6
Tritium ^g	20,000 pCi/L	20,000 pCi/L	<200–33,100	(h)

^a Human receptor. The more stringent concentration limits on this part of the table are shown in a larger typeface to illustrate that LLNL will comply with the most stringent requirements.

^b From NPDES Permit No. CA0029289 (revised 8/1/90) and RWQCB Order No. 90-106. VOC-specific State discharge limits exist in RWQCB Order No. 90-106 only for PCE (4 ppb) and benzene (0.7 ppb). Other VOCs listed in this table are included in the 5 ppb total VOC limit. Discharge limits for metals differ slightly according to discharge location.

^c Total trihalomethanes (THMs); includes chloroform, bromoform, chlorodibromomethane, and bromodichloromethane (California Drinking Water Requirement).

^d MCL is for either a single isomer or the sum of the ortho, meta, and para isomers.

^e National Interim Primary Drinking Water Regulation for total chromium is 50 ppb.

^f National Primary Drinking Water Regulation Enforceable Action Level (Federal Register, volume 56, number 110, June 7, 1991, p. 26460).

^g Thorpe *et al.* (1990) show that ground water in the one well that currently exceeds the tritium MCL will be naturally remediated long before it migrates offsite.

^h There is currently no NPDES discharge limit for tritium. LLNL will use the MCL for tritium as the discharge limit.

Recent investigations have identified some areas where tritium concentrations in unsaturated sediments at LLNL are significantly elevated. The only potentially significant transport pathway to human populations for this tritium is inhalation and skin absorption of tritiated water from direct soil evaporation or from water taken up by plants and released to the air by transpiration from plant leaves. Most of the areas where tritium has been detected are paved with asphalt, thereby limiting potential evaporation from soil and further downward migration by infiltration of rain water. Elevated tritium levels in transpired water have been measured in isolated areas at LLNL. Federal regulations prohibit emissions that would cause any member of the public to receive a maximum effective dose equivalent of more than 10 millirem/year from the air pathway. Screening-level calculations have been performed by LLNL using the standard EPA model AIRDOS-EPA and assumptions that maximize the calculated dose. These calculations, which include the use of transpired-water data containing tritium at the highest observed concentrations, indicate that any potential dose from any of the detected tritium in soils would not exceed 0.01% of the 10 millirem/year dose standard (Macdonald *et al.*, 1990).

Two EPA-approved remediation pilot studies are in progress at LLNL to investigate alternatives for removing and treating VOCs and gasoline from ground water and unsaturated sediment. LLNL has extracted and treated over 30 million gallons of ground water from the southwest part of the site by pumping it to the surface and treating it with an ultraviolet light (UV)/hydrogen peroxide system that destroys most of the VOCs. Most of this treated water has been returned to the local ground water just south of LLNL in a recharge basin, thereby conserving local ground water resources. The equivalent of about 2,200 gal of liquid FHCs have been removed by withdrawing vapor from unsaturated sediments in the Gasoline Spill Area. The vapors have been successfully treated onsite with thermal oxidation.

3. Scope and Role of Preferred Response Actions

The preferred remedial alternatives described in this report address VOCs, FHCs, chromium, and lead in ground water, and FHCs and VOCs in sediment above the water table. As described in Section 4.2.1, tritium at LLNL does not require remediation. There is no significant way for people to be exposed to the contaminants in the unsaturated sediments at LLNL except by migration of the contaminants to the ground water. The cleanup objectives for all contaminants originating at LLNL are to:

1. Prevent future human exposure to contaminated ground water and soil.
2. Prevent further migration of contaminants in ground water.
3. Reduce contaminant concentrations in ground water to levels below drinking water MCLs, and reduce the contaminant concentrations in treated ground water to levels below State discharge limits (Table 1).
4. Prevent migration in the unsaturated zone of those contaminants that would result in concentrations in ground water above an MCL.

5. Meet all discharge standards of existing permits for treated water and for air emissions from treatment systems.

The preferred alternatives will achieve these cleanup objectives by removing the hazardous compounds from the subsurface soil and water and treating them at the surface at several onsite facilities. Ground water extraction would stop further migration of contaminants in ground water and prevent any human exposure to them via water wells. The proposed ground water treatment facilities would use different remediation technologies for different contaminants and would be designed to reduce contaminant concentrations in the extracted ground water to levels below established RWQCB discharge standards. Ground water extraction and treatment would continue until the Federal and State Agencies agree that the remedial action objectives have been met. The target objective is to reduce the concentrations in the ground water after cleanup to levels below drinking water standards (Table 1). Volatile contaminants in the unsaturated zone would be removed by extracting them in vapor, which would be treated onsite. Atmospheric emissions from treatment systems would comply with Bay Area Air Quality Management District standards. Contaminants in the unsaturated zone would be remediated only if it is predicted that they would result in concentrations above an MCL if allowed to migrate into the ground water.

4. Summary of Site Risks

As part of the RI, a Baseline Public Health Assessment (Thorpe *et al.*, 1990, and now Layton *et al.*, 1990) was conducted to estimate potential future public health risks if contaminants in ground water and sediments originating at LLNL were not cleaned up. In addition, a risk assessment was conducted as part of the FS to estimate potential future public health risks if the concentrations of VOCs in ground water beneath the study area were reduced to their respective MCLs. These and other assessments of potential health risks for the LLNL site are summarized below. Refer to the RI and FS reports for details of the risk assessments.

In the assessment of risk for the LLNL site, a future residential-use scenario was not considered because it is unlikely that transfer of ownership of the site from DOE would occur in the foreseeable future. DOE commits in perpetuity that it will not allow the LLNL site to pose a public, occupational, or environmental hazard.

4.1. Potential Exposure Pathways

Potential exposure pathways for present and future offsite populations are (1) domestic use of contaminated well waters and (2) contact with surface water runoff or sediment in local arroyos that receive drainage waters from the LLNL site. For domestic water uses, the potential exposure pathways are ingestion, inhalation of VOCs that volatilize, and entry through the skin. For irrigation uses, the potential exposure pathways are inhalation from sprinklers and ingestion of foods in home gardens irrigated with water containing VOCs. The most important exposure pathways with regard to health risk are from domestic water use (Thorpe *et al.*, 1990).

The concentrations of hazardous materials in surficial soils onsite and offsite are not sufficient to be a carcinogenic health risk or a noncarcinogenic health hazard by any exposure pathway. There are no direct onsite exposures to contaminated surface or ground waters.

4.2. Assessment of Potential Risk

4.2.1. Non-VOCs and Ecological Impacts

The potential for exposure to the public to benzene and other FHCs in soil and ground water at LLNL is extremely limited. The sediments containing these compounds are limited to a small area in southern LLNL and are well below the ground surface. As a consequence, the public is not likely to come into direct contact with them. Because these compounds are below ground, volatilization and subsequent inhalation exposure is also not a concern. During vapor extraction, the vapors are treated to prevent public health risk. Furthermore, ground water contaminated with benzene and FHCs does not pose a public health risk because the water containing these compounds is entirely beneath DOE property and a portion of East Avenue, and is not used for any purpose. Therefore, FHCs do not pose a public health concern (Thorpe *et al.*, 1990).

Tritium levels in ground water have declined significantly over the past few years due to natural decay. Even if no remediation occurred, tritium levels would be reduced far below drinking water standards by the time tritium might migrate offsite in ground water (Thorpe *et al.*, 1990). Therefore, the best approach is to allow the tritium concentrations to decline naturally to levels below the MCL. Screening calculations of risks from tritium released from a potential LLNL air stripper for ground water treatment at the site of maximum tritium concentrations in ground water from monitor wells (MW-206), and from tritium transpired from onsite vegetation at the site of maximum soil tritium concentrations, show that the resulting potential tritium doses would not exceed 0.01% of the 10 millirem/year Federal dose standard (Macdonald *et al.*, 1990). Hence, tritium in soil and ground water at LLNL does not appear to pose a public health hazard.

Chromium occurs at LLNL in relatively small areas along with VOCs and will be removed and treated with the other contaminants. Chromium in concentrations above the MCL in the area northwest of LLNL will be investigated under RWQCB order by the party or parties potentially responsible for the offsite chromium. If LLNL is found to be the source of chromium in this area, LLNL will incorporate this area into the remedial design.

As discussed in Section 2, the limited extent and low migration potential for lead indicate that it does not pose a health threat.

Currently, there is no potential risk of ecological impacts related to the consumption of ground water, because no ground water containing contaminants is present at the surface, either onsite or offsite. No perennial streams exist at or near the site; thus, no streams receive flow from ground water.

4.2.2. VOCs

Potential risks from VOCs are assessed below for (1) a hypothetical no-remediation scenario and (2) a postremediation scenario in which all VOCs are reduced to their MCLs. Because all viable remedial alternatives will be designed to reduce VOC concentrations in ground water to MCLs, or lower, the calculated risks apply to all remedial alternatives. Health risks associated

with volatilization of compounds from the surficial soils at the LLNL site are shown to be negligible in the RI.

VOC concentrations in ground water predicted by computer modeling were used to calculate the carcinogenic health risk associated with the offsite migration of contaminants. To address uncertainties inherent in predicting contaminant migration in ground water, we simulated contaminant movement in two ways, as described in the RI. The “best-estimate” risks in Tables 2 and 3 are based on our current knowledge of the LLNL ground water system and contaminant properties, and represent the most probable scenario. The “health-conservative” risks in Tables 2 and 3 represent a worst-case scenario that is based on very conservative assumptions regarding contaminant migration and use of the contaminated water for domestic purposes. It is extremely unlikely the risks calculated for this scenario would ever be realized (see Thorpe *et al.*, 1990, for more information).

To determine the potential public health hazard from exposure to noncarcinogenic compounds, a hazard index (HI) was calculated. If the HI value is greater than 1.0, exposure could result in adverse health effects if there is an additive effect of all the compounds considered in the HI calculation (Isherwood *et al.*, 1990).

Uncertainties are associated with all estimates of cancer and non-cancer health hazards. These uncertainties result from incomplete knowledge of many physical and biological processes, such as carcinogenesis. Where specific information is not available, it is necessary to make assumptions and/or use predictive models to compensate for lack of information. The assumptions, models, and calculations are chosen such that the resulting risk and hazard estimates are health conservative. The specific sources of uncertainty in the risk and hazard estimates presented here are further discussed in Layton *et al.*, 1990.

4.2.2.1. No-Remediation Scenario

The maximum theoretical excess cancer risks for a hypothetical, no-remediation scenario, based on the assumption that an individual will use well water for a 70-year (lifetime) period, are presented in Table 2. The maximum additional cancer risk associated with the best-estimate scenario in Table 2 means that the cancer risk from a lifetime exposure to VOCs (PCE, TCE, chloroform, and carbon tetrachloride) in well water derived from a downtown Livermore municipal supply well could be as high as 7 in 10 million (7×10^{-7}), using EPA assessment methods. This means that each individual that consumes 2 liters of this water each day for 70

Table 2. No-remediation-scenario cancer risk and hazard index (HI) values using the EPA methodology^a (U.S. EPA, 1989a).

No-remediation scenario	Risk of cancer	HI
Best estimate	7×10^{-7}	1.6×10^{-3}
Health conservative ^b	2×10^{-3}	1.0
Health conservative ^c	1×10^{-3}	1.0

^aSee Isherwood *et al.* (1990) for an alternative method of computing the risk of cancer and HI.

^bBased on potential monitor well drilled 250 ft west of LLNL.

^cBased on receptor wells in downtown Livermore.

years would increase his risk of developing cancer by 7 in 10 million above the normal 1 in 4 cancer risk for Americans (U.S. EPA, 1989a). The HI associated with the best-estimate scenario is far below 1.0, indicating exposure at the predicted concentrations would not produce any adverse health effects from noncarcinogens (see Thorpe *et al.*, 1990, for details).

Under the health-conservative scenario, the maximum additional cancer risk is two in one thousand (2×10^{-3}) for a lifetime exposure to contaminants in water from a potential monitor well drilled 250 ft west of LLNL. The HI calculated for this scenario is 1.0. Because no drinking water wells are likely to be drilled in the area 250 ft west of LLNL, we also calculated the risk based on a lifetime exposure to well water derived from downtown Livermore using the health conservative assumptions. This unlikely scenario results in a maximum additional cancer risk of one in one thousand (1×10^{-3}) and an HI of 1.0. The HI of 1.0 for the health-conservative scenario indicates that there is no hazard of noncarcinogenic health effects. Both health conservative risks in Table 2 exceed EPA's one in ten thousand to one in one million (1×10^{-4} to 1×10^{-6}) acceptable risk range for Superfund sites.

4.2.2.2. After Remediation

The maximum additional cancer risks and the HI that may apply after remediation is complete are presented in Table 3. Under the best-estimate scenario, the maximum additional cancer risk in Table 3 means the additional cancer risk is seven in one hundred million (7×10^{-8}). This is over 100 times lower than the one in ten thousand to one in one million (1×10^{-4} to 1×10^{-6}) acceptable level of risk specified in the National Contingency Plan (U.S. EPA, 1990). The HI for this scenario is far less than 1.0, indicating that no adverse health effects from noncarcinogens would occur after remediation.

Under the health-conservative scenario, the maximum additional cancer risk is four in one hundred thousand (4×10^{-5}) for a lifetime exposure to water derived from a well 250 ft west of LLNL. The maximum additional cancer risk is three in one hundred thousand (3×10^{-5}) for a lifetime exposure to water from a well in downtown Livermore. The HIs for either health conservative scenario are well below 1.0, indicating that no adverse health effects are associated with exposure to noncarcinogens after remediation.

In summary, the identified compounds of concern, if not addressed by the preferred alternatives or other considered measures, may present a potential risk to public health.

Table 3. Postremediation cancer risk and hazard index (HI) values using the EPA methodology^a (U.S. EPA, 1989a).

Remediation scenario	Risk of cancer	HI
Best estimate	7×10^{-8}	8.3×10^{-5}
Health conservative ^b	4×10^{-5}	2.7×10^{-2}
Health conservative ^c	3×10^{-5}	3.1×10^{-2}

^aSee Isherwood *et al.* (1990) for an alternate method of computing the risk of cancer and HI.

^bBased on potential monitor well drilled 250 ft west of LLNL.

^cBased on receptor wells in downtown Livermore.

5. Summary of Alternatives

In the FS, three remedial alternatives were assembled from the viable treatment options for ground water for the LLNL site:

1. *Ground water extraction throughout the contaminated area, including source areas, thereby preventing further contaminant migration and enabling the most rapid cleanup.* Ground water would be treated at the surface using UV/oxidation or air stripping-based technology with granular-activated carbon (GAC) to prevent any measureable air emissions. The treated water would be recharged or used at the LLNL site.
2. *Ground water extraction at the downgradient edges of contamination to prevent further contaminant migration.* Ground water would be treated at the surface, as for Alternative No. 1, and recharged or used at the LLNL site.
3. *Ground water monitoring and treatment at the point of use, if drinking water supply wells should ever contain contaminants from LLNL in concentrations above drinking water standards.* Ground water would be treated at the surface, as described in No. 1 above.

The remedial alternatives considered for contaminants in the unsaturated sediment are:

1. *Vacuum-induced venting with surface treatment of vapors using GAC, thermal oxidation, or catalytic oxidation.*
2. *Deferring action to see if contaminants migrate to the ground water, and, if they do, extracting and treating the ground water as described for the ground water remedial alternatives.*

A third alternative, excavation and treatment and/or disposal, was also considered for unsaturated sediment. However, this alternative would be applicable only if (1) contaminant concentrations are found in the unsaturated zone that are high enough to cause significant concentrations in the ground water, and (2) they occur at relatively shallow, accessible depths. Currently, no known locations meet these criteria, and this alternative is not considered further in this report. However, excavation, treatment, and/or disposal could be employed in the future if high concentrations of contaminants, treatable perhaps by bioremediation or aeration, are discovered at excavatable depths.

The FS discusses the various technologies for treating extracted ground water and vapor and assembles them into treatment options. The preferred treatment options vary from place to place because different parts of the site contain somewhat different combinations of contaminants in ground water and unsaturated sediment, as described in Sections 5.2 and 5.3 of this report.

All the remedial alternatives considered for the LLNL site would include long-term ground water monitoring and reporting, in compliance with CERCLA requirements, until demonstrated achievement of the remedial action objectives. The costs of these activities, which are common to all alternatives for their respective estimated times of operation, were not explicitly addressed in the FS, but are presented here to reflect the additional costs of maintaining a remediation program into the distant future. These additional costs are significant when comparing alternatives with project lives that differ by many decades. Monitoring activities will be conducted and reviewed periodically to gauge the effectiveness of the remedies. For all alternatives, the costs and implementation times are estimated using the assumptions discussed in

the FS. The program operations costs, which were not described in the FS, are summarized in Appendix A of this report.

All the treatment options for ground water will reduce the effluent concentration of VOCs, FHCs, chromium, and lead below Applicable or Relevant and Appropriate Requirements (ARARs) (Isherwood *et al.*, 1990). Tables 3-1 and 3-2 in the FS summarize the ARARs for the LLNL site. For treatment options that include disposal of treated ground water or air emissions, the effluent concentrations will be in compliance with RWQCB Waste Discharge Requirements, National Pollutant Discharge Elimination System, and Bay Area Air Quality Management District standards. Treated ground water will be recharged at the LLNL recharge basin south of East Avenue, in local drainage ditches and arroyos, or in infiltration trenches or recharge wells. Treated water will also be used for onsite landscape irrigation and in LLNL's cooling towers. No treated ground water will be recharged back to the subsurface if the tritium level exceeds the MCL.

Treatment options utilizing air stripping will be designed with GAC on the effluent air stream, so there are no measurable air emissions. For those options employing GAC to treat water or air streams, the GAC will be shipped offsite where it will be commercially regenerated to destroy or recycle, if possible, the absorbed contaminants. Options employing ion exchange for treatment of metals would require offsite recycling or disposal of the ion-exchange resin as a hazardous waste.

5.1. No-Action Alternative

A No-Action Alternative was considered in the FS for the LLNL site to establish a baseline for comparison. Under this alternative, LLNL would cease all characterization and remedial activities. Limited ground water monitoring would continue to track changes in ground water chemistry. The No-Action Alternative is not the same as the Deferred-Action Alternatives discussed in Sections 5.2.3 and 5.3.2, in that remedial actions may be taken in the future under the Deferred-Action Alternatives. The No-Action Alternatives for ground water and unsaturated sediment do not meet Federal and State standards to protect human health and are not considered further in this report.

Deferred-Action Alternatives are discussed below for ground water and unsaturated sediment. In each case, future actions may be taken if continued monitoring indicates they are necessary. These Deferred-Action Alternatives, however, are not considered "no-action" because future measures may be taken to protect human health.

5.2. Ground Water Remedial Alternatives

Two ground water extraction plans that use different arrays of extraction wells form the basis for immediate-action alternatives to remediate ground water. Each extraction plan is discussed subsequently with its remedial alternative.

Costs for the ground water remedial alternatives are summarized in Table 4. In the FS, costs were analyzed using a present worth calculation procedure, as prescribed by EPA for comparing remedial alternative costs. This is the standard procedure for comparing alternatives with costs and revenues beginning, ending, or extending over different periods of time. This procedure involves discounting future costs to reflect the time value of money. We used EPA's

Table 4. Summary of costs for ground water remedial alternatives for the LLNL Livermore site.

Remedial alternative	Present worth costs (millions of 1990 dollars) ^a				Undiscounted costs (millions of 1990 dollars) ^b	
	Capital costs ^c	Treatment system O&M costs ^d	Program operations ^e	Total present worth of alternative ^f	Average annual costs ^g	Total undiscounted costs ^h
Remedial Alternative No. 1 50-year operation—UV/oxidation treatment at Treatment Facilities A, B, E, and F; air stripping primary treatment at Treatment Facilities C, D, and G	9	21	73	103	5	255 ⁱ
Remedial Alternative No. 2 90-year operation—UV/oxidation treatment at Treatment Facilities A, B, and F; air stripping primary treatment at Treatment Facility C	6	14	79	99	5	423 ^j
Remedial Alternative No. 3a ^k 30-year operation beginning in 200 years; air stripping treatment at the point of distribution in Livermore	0.01	0.03	87	87	2	403 ^l
Remedial Alternative No. 3b ^m Monitoring 10 wells for 100 years	0.00	0.00	12	12	0.6	61 ⁿ

^a Present worth calculated using a 5% discount rate for Remedial Alternative No. 1 over 50 years and Remedial Alternative No. 2 over 90 years; and, for Remedial Alternative No. 3, a 5% rate for a 30-year operation and then at a 2% rate for 200 years from possible commencement of treatment to 1990 for operation and maintenance, and 230 years for program operations.

^b Undiscounted costs (in 1990 dollars) that do not take into account the time value of money, inflation, profit, or the cost of money; these costs are intended to describe the magnitude of yearly costs relative to 1990 measures of value (see Appendix A).

^c Total capital costs of treatment systems, extraction wells, pipelines, water recharge and reuse facilities, monitor wells, and piezometers.

^d Present worth of annual operating and maintenance costs of treatment systems, extraction wells, pipelines, water recharge and reuse facilities, monitor wells, and piezometers.

^e Present worth of annual program operations; see Appendix A for details.

Table 4. (Continued).

^f Sum of present worths of capital costs, treatment systems, operating and maintenance, and program operations.

^g The average annual undiscounted costs of fixed and variable O&M, well replacement and closure, and program operations over the expected operating life of the alternative.

^h The total of all undiscounted costs.

ⁱ Average annual current-year costs times 50 years, the expected operation time for Remedial Alternative No. 1.

^j Average annual current-year costs times 90 years, the expected operation time for Remedial Alternative No. 2.

^k Cost estimate for this alternative assumes that VOCs could migrate to Livermore municipal-supply wells in 200 years, if ever. Program operations costs are assumed to be \$1.75 million per year.

^l Average annual operation and maintenance times 30 years, the expected operation time, if needed, plus annual program operations costs times 230 years (200 years for monitoring and 30 years for remediation and monitoring).

^m Assumes lower program operations costs, \$0.6 million per year, monitoring of 10 wells for 100 years, and no treatment because computer modeling predicts that VOCs in ground water may never exceed MCLs in Livermore municipal-supply wells.

ⁿ Average annual monitor well operations and maintenance and program operations costs times 100 years.

recommended discount rate of 5% to calculate the present worth.¹ The discounting procedure has the effect of downplaying the apparent importance of future costs. Estimating the present value of future expenditures can involve not only the time value of money, but the reduction in the value of money—inflation—and long-term price increases resulting from market and technology forces. All of these factors are difficult to anticipate. However, to give some idea of the estimated expenditure relative to 1990 measures of value, we also show undiscounted costs (in 1990 dollars) in Table 4. The actual dollars required in future years (referred to as “current year dollars”) will be even greater because the dollar will gradually lose value as a result of inflation.

As seen in Table 4, the cost comparison is highly dependent on the discounting procedure, especially when projects extend into the distant future. The choice of discount rate can even change the relative expense of the alternatives presented in Table 4. In general, projects that extend significantly longer into the future will require greater expenditure of current year dollars, but those dollars will be worth less as a result of inflation and the time value of money. The cost comparison between Remedial Alternatives Nos. 1 and 2 depends critically on the discount factor used. The actual future trends in financial factors that could provide an accurate discount factor (such as the real discount rate and inflation) are not predictable with sufficient confidence to demonstrate a significant difference between the present worths of these two alternatives. However, Alternative No. 2 will cost significantly more in current year dollars over its 90-year life than Alternative No. 1 over 50 years.

5.2.1. Ground Water Remedial Alternative No. 1

5.2.1.1. Ground Water Extraction Plan for Remedial Alternative No. 1—Complete Capture and Source Area Extraction

Under this plan, extraction wells would be strategically placed near contaminant margins to intercept and hydraulically control all ground water originating from LLNL with VOC concentrations exceeding MCLs. In addition, ground water would be extracted from source areas to expedite cleanup. This plan would utilize 18 extraction locations and 7 treatment facilities shown conceptually on Figure 7. A plot of the predicted ground water flow patterns using these wells is shown in Figure 8. The flow lines (with arrows on Fig. 8) converge on extraction locations and show the areas hydraulically captured by the extraction wells. The total rate of ground water removal for this extraction plan is estimated to be about 350 gallons per minute (gpm). Where VOCs and tritium occur together in ground water, our goal is to design extraction systems that will prevent the water influent to any treatment systems from containing tritium in concentrations above the MCL. Therefore, no tritium will be released from treatment systems in concentrations above the MCL.

¹ In the case of the Deferred-Action Alternative, we used a discount rate of 5% for the possible 30-year operation and a rate of 2% for the 200 years before treatment may be necessary.

Figure 7

Figure 8

We estimate that it would take about 50 years to reduce contaminant concentrations to MCLs using this approach and that all extraction and treatment facilities would be operational in the 1993-94 timeframe, depending on DOE and congressional funding.

5.2.1.2. Treatment Options for Ground Water Remedial Alternative No. 1

5.2.1.2.1. Ground Water Containing VOCs (Proposed Treatment Facilities A, B, C, E, and G) (Fig. 7). Treatment Facility E could potentially receive ground water containing tritium as well as VOCs.

Treatment Option 1. Granular-activated carbon (GAC). Ground water pumped by extraction wells would pass through beds of activated carbon where VOCs would be removed by GAC. The operating costs of this treatment option are high.

Treatment Option 2. Air Stripping with GAC Treatment of the Vapor. Ground water pumped by extraction wells would pass through an air stripper where VOCs would be removed by transferring them from the water to the air. The vapors from the stripper would pass through GAC to completely remove contaminants. This treatment option is the most economical for ground water containing VOCs.

Treatment Option 3. UV/Oxidation Plus Air Stripping with GAC Filtering of the Vapor. Extracted ground water would be blended with small amounts of hydrogen peroxide and exposed to strong ultraviolet (UV) light, destroying most of the contaminants. LLNL pilot studies have shown that some compounds require secondary treatment by air stripping, which would be added to treat water after it passed through the UV/oxidation unit. The vapors from air stripping would pass through GAC to remove contaminants. This option reduces the amount of waste requiring further treatment or disposal, especially where the majority of the contaminants are readily oxidized by the UV/oxidation process. Costs for this option are moderately high.

Treatment Option 2 or 3 is preferred for Treatment Facilities A, B, C, E, and G, depending on the concentrations and types of the compounds, and the flow rate influent to each treatment facility.

5.2.1.2.2. Ground Water Containing VOCs and Chromium (Proposed Treatment Facility D) (Fig. 7)

Treatment Option 1. GAC Plus Ion Exchange. Ground water pumped by extraction wells would pass through GAC beds, which would remove the VOCs. The VOC-free water would then be fed through an ion-exchange resin to extract chromium. The operating costs of this treatment option are high.

Treatment Option 2. Air Stripping with GAC Filtering of the Vapor Phase Plus Ion Exchange. Extracted ground water would pass through an air stripper to remove VOCs. The vapors from the stripper would pass through GAC to remove VOCs from the air. The VOC-free water would be fed through an ion-exchange resin to extract chromium. This treatment option is preferred because the higher concentrations of TCE, carbon tetrachloride, chloroform, and Freon 113 make this treatment option more economical.

Treatment Option 3. UV/Oxidation Plus Air Stripping and Ion Exchange with GAC Treatment of the Vapor. Extracted ground water would be blended with small amounts of hydrogen peroxide and exposed to strong UV light, destroying most of the VOCs. Remaining VOCs would be removed from the water by air stripping. The vapors from the air stripper would pass through GAC to completely remove VOCs. The VOC-free water would then be fed through an ion-exchange resin to extract chromium. The operating costs of this treatment option are high.

5.2.1.2.3. Ground Water Containing FHCs, VOCs, and Lead (*Proposed Treatment Facility F*) (Fig. 7)

Treatment Option 1. GAC Treatment. Ground water pumped by extraction wells would pass through GAC beds, which remove the FHCs, VOCs, and lead. The operating costs of this treatment option are high.

Treatment Option 2. Air Stripping with GAC Treatment of Both the Vapor and Liquid Phases. Extracted ground water would pass through an air stripper to remove FHCs and VOCs. The vapors from the stripper would pass through GAC to completely remove FHCs and VOCs. The water would then pass through GAC to extract lead and any remaining FHCs or VOCs. This treatment option is not preferred because the high concentration of FHCs would require frequent carbon regeneration that increases the operating costs of this treatment option substantially.

Treatment Option 3. UV/Oxidation Plus GAC. Extracted ground water would be blended with small amounts of hydrogen peroxide and exposed to strong UV light, destroying most contaminants. The water would then pass through GAC beds to remove lead and any remaining FHCs or VOCs. This treatment technology is preferred because it can handle the high concentrations of fuel hydrocarbons. It is also the most economical of the treatment options.

Treatment Option 4. Subsurface Bioremediation. Biological treatment would utilize the metabolic destruction of organic compounds by microbes that convert the organic compounds in the ground water to less toxic compounds. Bioremediation of the FHCs in the Gasoline Spill Area is potentially viable. However, the relatively great depth of FHCs at LLNL, which makes providing the correct physical and chemical conditions for the microbes difficult, and the sensitivity of microorganisms to subsurface conditions that are difficult to control, make applicability of subsurface bioremediation at LLNL uncertain. In addition, bioremediation has not yet been proven successful for chlorinated VOCs. Therefore, this treatment option is not considered further as an initial remedial action.

5.2.2. Ground Water Remedial Alternative No. 2

5.2.2.1. Ground Water Extraction Plan for Remedial Alternative No. 2—Downgradient Control

Under this plan, extraction wells would be placed along the western boundary of LLNL to intercept and hydraulically control the offsite migration of those VOCs in concentrations exceeding MCLs. In addition, extraction would also occur in the Gasoline Spill Area, where a pilot remediation study is ongoing, and in the adjacent Building 518 Area to prevent migration of

FHCs and VOCs to the south of LLNL. This plan would use extraction locations 1 through 7 and location 9 in and near the western boundary of LLNL and locations 17 and 18 in the southeastern part of LLNL (Fig. 7). Extracted water would be treated at Treatment Facilities A, B, C, and F (Fig. 7). A plot of the predicted ground water flow patterns using the extraction locations for this plan is shown in Figure 9. The rate of ground water extraction for this plan is estimated to be about 200 gpm. We estimate that it would take more than 90 years to achieve MCLs under this plan and that all extraction and treatment facilities would be operational in 1993.

5.2.2.2. Treatment Options for Ground Water Remedial Alternative No. 2

This alternative differs from Alternative No. 1 in that fewer extraction locations and treatment facilities would be employed. The treatment options discussed in Section 5.2.1 for Treatment Facilities A, B, C, and F would be identical for this alternative.

5.2.3. Ground Water Remedial Alternative No. 3—Deferred Action

For the Deferred-Action Remedial Alternative, ground water would not be treated until *and unless* contaminants in concentrations greater than MCLs migrate to a drinking water supply well, such as those operated by the California Water Service Company, located about 2 miles west of LLNL. Under this alternative, treatment would take place at the point of distribution for the affected water-supply system. If contaminants do reach supply wells, probably no sooner than about 200 years, their concentrations would be substantially lower than those at LLNL (Thorpe *et al.*, 1990). The ground water would be treated, at a minimum, to conform to the MCLs for each contaminant before it is distributed for human consumption. Selection of an appropriate treatment option would be made at the time that treatment may be necessary because technology and economics may have changed considerably by then. Currently available options are presented below for comparison.

5.2.3.1. Treatment Options for Ground Water Remedial Alternative No. 3

Treatment Option 1. GAC Treatment. Ground water pumped by water-supply wells would pass through GAC beds to remove contaminants.

Treatment Option 2. Air Stripping. Ground water pumped by water-supply wells would pass through an air stripper. Because only very low concentrations of VOCs may ever occur in water from supply wells (Thorpe *et al.*, 1990), treatment of air emissions would most likely be unnecessary. This treatment option is preferred because concentrations of compounds will be very low and it is the most economical of the treatment options.

Treatment Option 3. UV/Oxidation. Ground water pumped by water-supply wells would be blended with small amounts of hydrogen peroxide and exposed to strong UV light to destroy VOCs. We expect the concentrations of VOCs would be reduced sufficiently so that secondary treatment would be unnecessary.

Figure 9

5.2.4. Comparison of Ground Water Treatment Option Costs

For each extraction and treatment alternative described above, several treatment technology options passed initial screening and were subjected to a detailed evaluation in Section 4 of the FS. For purposes of comparing the treatment technologies in the FS, cost estimates were prepared (see Appendices D, E, and F of the FS) using EPA's suggested 30-year operating and maintenance period (EPA, 1989b). A supplemental analysis was conducted for several of the treatment facilities assuming 90 years of operation would be required for Alternative No. 2 to achieve ARARs. This detailed analysis indicates that, in general, for the same length of operation (e.g., 30 years), (1) GAC is about 1.8 times more expensive in present worth for a treatment facility than air stripping and (2) ultraviolet light/oxidation treatment is 1.3 times as expensive in present worth as air stripping. Alternative No. 3 has a very low present worth, ranging from \$30,000 for air stripping to \$280,000 for GAC, largely because the long time span prior to possible commencement of treatment reduces the total costs of this alternative by a factor of 0.019 in the discounting procedure. This also takes into account the different combinations of contaminants and treatment options at each treatment facility.

In summary, GAC is generally the most costly treatment technology, followed by UV/oxidation, and then by air stripping. However, the costs in the FS do not include the program operations costs in Appendix A. These costs do not significantly affect the relative costs of the treatment options, but they are significant in magnitude when comparing remedial alternatives with different periods of operation. We have added the program operations costs to the remedial alternatives discussed in this report to more completely estimate the total cleanup costs.

5.3. Unsaturated Zone Alternatives

Costs of remedial alternatives for the unsaturated zone are summarized in Table 5. The remedial alternatives and treatment options are described below.

5.3.1. Unsaturated Zone Remedial Alternative No. 1— Vacuum-Induced Venting

Current data indicate that only FHCs in the Gasoline Spill Area, VOCs in the Building 518 Area in the southeastern part of the LLNL site, and possibly VOCs in the vicinity of the East Taxi Strip in eastern LLNL will need unsaturated zone remediation (Isherwood *et al.*, 1990). FHCs and/or VOCs would be removed from the subsurface by vacuum-induced venting using extraction wells. Treatment options for the extracted vapor are described in the following section. If vapor extraction were ever considered for any of the localized areas at LLNL where elevated levels of tritium occur in the unsaturated zone, the water portion of the vapor could be (1) released to the atmosphere or (2) separated from the vapor by condensation. For possible tritium air releases from treatment systems, we would use the AIRDOS-EPA computer model to evaluate the potential annual dose to a hypothetical maximally exposed individual. LLNL will shut down any treatment system that emits tritium to the atmosphere at a rate predicted to cause exposure of greater than 10 millirem/year (the Federal standard for clean air).

Table 5. Summary of costs for unsaturated zone remedial alternatives for the LLNL Livermore site.

Remedial alternative	Present worth costs (thousands of 1990 dollars) ^a				Undiscounted costs (thousands of 1990 dollars) ^b	
	Capital costs ^c	Treatment system O&M costs ^d	Program operations ^e	Total present worth of alternative	Average annual costs ^f	Total undiscounted costs ^g
Remedial Alternative No. 1 Immediate action—10-year operation; vapor withdrawal and catalytic oxidation treatment; vapor from Building 518 piped to Treatment Facility F ^h	529	585	0	1,114	141	1,406 ⁱ
Remedial Alternative No. 2 Deferred action ^j —monitor and extract and treat ground water, if necessary	0	252 ^k	600 ^l	852	587	23,488 ^m

^aPresent worth calculated using a 5% discount rate for Remedial Alternative No. 1 over 10 years; and, for Remedial Alternative No. 2, , a 5% rate for 50 years from possible commencement of treatment in 1990, and a 5% rate for 40 years of operation.

^b Undiscounted costs (in 1990 dollars) that do not take into account the time value of money, inflation, profit, or the cost of money; these costs are intended to describe the magnitude of yearly costs relative to 1990 measures of value.

^c Total capital costs of treatment systems, extraction wells, and monitor wells.

^d Present worth of annual operating and maintenance costs of treatment systems, extraction wells, and monitor wells.

^e Included with ground water remediation only because the major remediation is associated with ground water.

^f The average annual undiscounted costs of fixed and variable O&M, replacement and closure, and program operations over the expected operating life of the alternative.

^g The total of all undiscounted costs.

^h The present worth of extracting and piping vapor from the Building 518 Area to Treatment Facility F is \$175,000 for 5 years of operation (including O&M) necessary to achieve ARARs. The present worth of installing a separate catalytic oxidation unit at the Building 518 Area and operating it for 5 years is \$1,100,000 (including O&M).

ⁱ Average annual current-year costs times 10 years, the expected operation time for Remedial Alternative No. 1.

Table 5. (Continued).

^j Assumes a 50–60-year period before VOCs and/or FHCs migrate to ground water from unsaturated zone in concentrations above MCLs. Treatment by UV/oxidation at Treatment Facility F for 40 years beginning in 50 years (equivalent to the difference between Remedial Alternatives No. 1 and 2 at Treatment Facility F).

^k Does not include costs of additional monitoring, extraction, or recharge wells or piezometers that may be necessary.

^l Ten percent of program operations costs charged to this alternative from years 51 through 90 because they would not otherwise be necessary ($4,000,000 \times 0.1 \times 1.5$ discount factor present worth of annual expenses from years 51 to 90).

^m Average annual current-year costs times 40 years, the expected operation time for Remedial Alternative No. 2.

We estimate that it would take about 10 years to remediate the unsaturated zone under this alternative and that remediation would be underway by late 1992.

5.3.1.1. Treatment Options for Unsaturated Zone Remedial Alternative No. 1

Treatment Option 1. GAC Treatment. Vapors from vent wells would pass through a chamber containing GAC to remove VOCs or FHCs. The treated vapor would be discharged to the atmosphere.

Treatment Option 2. Thermal Oxidation. Vapors from vent wells would pass through a thermal oxidation chamber where the FHC and VOC vapors would be oxidized with the assistance of a heat source such as propane. The VOCs and FHCs would be destroyed and treated air would be discharged to the atmosphere.

Treatment Option 3. Catalytic Oxidation. Vapors from vent wells would be heated and passed through a catalyst, where organic compounds would be converted to harmless oxidation products, such as carbon dioxide and water. The treated air would be discharged to the atmosphere. A catalyst suitable for both VOCs and FHCs has recently been found. The rationale for preferring catalytic oxidation over thermal oxidation for treatment of vapors is presented in Appendix B. If use of catalytic oxidation results in emission of vapors with compounds above regulatory standards, secondary treatment or alternative technology, such as GAC, will be evaluated and implemented to comply with regulatory standards.

5.3.2. Unsaturated Zone Remedial Alternative No. 2—Deferred Action

Under this alternative, all contaminants in the unsaturated zone would be left in place and allowed to degrade, volatilize, or migrate to ground water under natural conditions. Ground water would continue to be monitored according to the requirements of CERCLA. If any contamination of ground water above MCLs occurs, it would either be remediated by ongoing ground water extraction and treatment, or by additional ground water extraction and treatment systems, if necessary.

5.3.3. Comparison of Unsaturated Zone Treatment Option Costs

The relative present worth costs for the three vadose zone treatment options are discussed in Section 4 of the FS. In summary, the present value of GAC is about 50% greater than for thermal oxidation, and catalytic oxidation is about 20% less than thermal oxidation.

6. Evaluation of Alternatives and the Preferred Alternatives

6.1. The Preferred Alternatives

Ground Water Remedial Alternative No. 1 is the preferred alternative for the LLNL site. It is comprised of:

1. Immediate action, consisting of ground water extraction at 18 locations, to completely capture all contaminants originating at LLNL and extract ground water in source areas.
2. Construction and operation of seven onsite facilities to treat extracted ground water.
3. Use of the UV/oxidation-based remediation technology at Treatment Facilities A, B, E, and F (Fig. 7), and air stripping-based technology at Treatment Facilities C, D, and G. Air stripping-based remediation technology is preferred at Treatment Facilities C, D, and G because there are higher concentrations of compounds such as chloroform, carbon tetrachloride, Freon 113, and 1,1,1-TCA, which are less effectively treated by UV/oxidation, thereby eliminating its waste minimization advantage (See Table 3-9 in the FS).

Unsaturated Zone Remedial Alternative No. 1 is the preferred alternative for those sites with contaminants likely to reach ground water and result in concentrations greater than ARARs, and consists of vacuum extraction and treatment of the extracted vapor by catalytic oxidation. Selection of these alternatives is preliminary and could change in response to public comments or new information.

6.2. Evaluation Criteria

The EPA has established nine criteria for evaluating remedial alternatives (U.S. EPA, 1988; 1989b). These criteria are summarized in Figure 10. Items 1 and 2 on Figure 10—protection of human health and the environment, and compliance with ARARs—are threshold criteria, which must be satisfied for an alternative to be eligible for selection. Items 3 through 7—long-term effectiveness and permanence, short-term effectiveness, reduction in toxicity, mobility and volume, implementability and cost—are primary balancing criteria used to weigh major tradeoffs among alternatives. Items 8 and 9 on Figure 10—State and community acceptance—are modifying factors, which are formally taken into account after public and regulatory comment is received on the PRAP, although they influence the design and selection throughout the remediation planning process.

6.3. Rationale for Selecting the Preferred Alternatives

The remedial alternatives and associated treatment options were evaluated against nine EPA criteria in the FS (Isherwood *et al.*, 1990). The preferred remedial alternatives for ground water and unsaturated sediment are analyzed below in terms of these nine criteria and are summarized in Tables 6 and 7.

6.3.1. Ground Water

Overall Protection of Human Health and the Environment. All the remedial alternatives, in conjunction with any of the treatment options, are equally protective of human health and the environment because each is designed to meet the same cleanup criteria (Isherwood *et al.*, 1990). For example, the design criteria for the treated ground water for all alternatives stipulate that total VOCs will not exceed 5 ppb. Each treatment option is designed to reduce individual VOC concentrations in the treated ground water to their MCLs or less. Consequently, the

Figure 10

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tables could be shown on facing pages.**

Table 6. Comparison of ground water remedial alternatives for the LLNL Livermore site^a.

Remedial alternative/ treatment options	Protective of human health and the environment	Comply with ARARs	Long-term effectiveness
<p>Remedial Alternative No. 1^b</p> <p>UV/oxidation-based systems for Treatment Facilities A, B, E, and F.</p> <p>Air stripping-based systems for Treatment Facilities C, D (plus ion exchange), and G.</p>	<p>Risk is reduced by design criteria that are lower than ARARs.</p> <p>Reduces ground water contaminant concentrations to MCLs; design criteria for treated ground water are lower than discharge limits.</p>	Meets all ARARs.	Effective.
<p>Remedial Alternative No. 2</p> <p>UV/oxidation-based systems for Treatment Facilities A, B, and F.</p> <p>Air stripping-based system for Treatment Facility C.</p>	<p>Risk is reduced by design criteria that are lower than ARARs.</p> <p>Reduces ground water contaminant concentrations to MCLs; design criteria for treated ground water are lower than discharge limits.</p>	Meets all ARARs.	Effective.
<p>Remedial Alternative No. 3</p> <p>Deferred treatment—Air stripping at point of distribution, if necessary.</p>	<p>Risk reduced by treatment at point-of-distribution (if necessary). Ground water quality would be degraded until treatment begins or concentrations naturally fall below MCLs.</p>	Does not fully satisfy the State of California ARAR concerning non-degradation of water resources.	Effective.

^a Using the nine EPA criteria for detailed evaluation of alternatives (U.S. EPA, 1988, pp. 6-1 to 6-31); State and local acceptance to be addressed during Record of Decision process.

^b LLNL Preferred Alternative.

^c Present worth is calculated to reflect the time value of money in excess of inflation, as described in Section 5.2.

^d If monitoring of ground water only were to be conducted for 100 years, the present worth cost would be \$12 million.

UV = Ultraviolet light.

Reduce toxicity, mobility, and volume or mass	Short-term effectiveness	Implementability (technical and administrative)	Present worth cost^c
Reduced as far as current technology permits.	Negligible impacts during installation and operation. About 50 years required to achieve MCLs in ground water.	Implementable.	\$103 million
Allows migration of contaminants across LLNL site.	Negligible impacts during installation and operation. Ninety or more years required to achieve MCLs in ground water.	Implementable.	\$99 million
Reduces volume by natural degradation. Allows migration of contaminants beyond present extent.	Remediation deferred until or unless VOCs impact in-use water supplies. Negligible impacts during installation and operation. Estimated 360 years for natural degradation to reduce contaminant concentrations below MCLs, and 30 years to achieve MCLs after treatment commences in 200 years, if necessary.	Implementable. Alternative may not be acceptable to regulatory agencies because it delays remediation an estimated 200 years.	\$87 million ^d

Table 7. Comparison of remedial alternatives for contaminants in the unsaturated zone for the LLNL

Remedial alternative	Protective of human health and the environment	Comply with ARARs	Long-term effectiveness
Immediate Action			
Vacuum extraction and catalytic oxidation ^b .	Risk reduced by design criteria.	Meets all ARARs.	Effective.
Deferred Action			
Remove contaminants that have migrated to ground water by extraction and treatment at the nearest treatment facility.	Risk to humans not actively reduced until VOCs or FHCs migrate to ground water. Ground water quality would be degraded until treatment begins or natural processes reduce concentrations below MCLs.	Does not fully satisfy a State of California ARAR concerning non-degradation of water resources where migration to ground water will result in concentrations greater than MCLs.	Effective.

^a Using the nine EPA criteria for detailed evaluation of alternatives (U.S. EPA, 1988, pp. 6-1 to 6-31); State and local acceptance to be addressed during ROD process.

^b LLNL Preferred Alternative.

^c Present worth is calculated to reflect the time value of money in excess of inflation, as described in Section 5.2.

Livermore site^a.			
Reduce toxicity, mobility, and volume or mass	Short-term effectiveness	Implementability (technical and administrative)	Present worth cost^c
Reduced as far as current technology permits.	Negligible impacts during installation and operation. About 10 years required to achieve Remedial Action Objectives.	Implementable.	\$1.1 million
Does not reduce contaminant mobility in the unsaturated zone. Volume reduced by natural degradation in an estimated 90 years.	Effective for both VOCs and FHCs; as much as 90 years required to achieve Remedial Action Objectives.	Implementable.	\$0.9 million

resulting health risks are identical among the remediation technology options (Isherwood *et al.*, 1990). Since Alternatives 2 and 3 would allow some continued migration of VOCs in ground water, they also allow some degradation of the subsurface environment.

Compliance with ARARs. Remedial Alternatives No. 1 and No. 2, in conjunction with any of the treatment options, are designed to achieve all ARARs (Isherwood *et al.*, 1990). However, Alternative No. 2 would allow higher-concentration VOCs in eastern LLNL to migrate across the site.

The Deferred-Action Remedial Alternative No. 3, treat at point-of-use, though estimated to be protective of human health (Isherwood *et al.*, 1990), does not fully satisfy the State of California ARAR concerning nondegradation of water resources.

Long-Term Effectiveness and Permanence. All three remedial alternatives, when combined with any of the treatment options, are equally effective in terms of permanence and stability of remediation and reduction in health risks by the ultimate destruction of contaminants.

Reduction in Toxicity, Mobility, and Volume. Remedial Alternatives No. 1 and No. 2, in conjunction with any of the treatment options, reduce toxicity, mobility, and volume of the compounds. Alternative No. 2 allows VOCs in eastern LLNL to migrate across the site. Remedial Alternative No. 3, deferred action, does not reduce contaminant mobility until and unless contaminants reach domestic or municipal wells in concentrations above an MCL. An advantage of the UV/oxidation remediation technology (preferred at Treatment Facilities A, B, E, and F) is that TCE, PCE, 1,1-DCE, and FHCs are destroyed in one process, thereby minimizing waste requiring further treatment or disposal. Use of GAC requires regeneration of spent carbon to convert the captured compounds to harmless substances, which would be conducted offsite. Ion-exchange resins for metals removal may require disposal as hazardous waste.

Short-Term Effectiveness. All the remedial alternatives would expose workers, the public, and the environment to negligible impacts during installation and operation.

The preferred remedial alternative is estimated to achieve the remediation goals in about 50 years compared to 90 years or more for Remedial Alternative No. 2, which employs only four treatment facilities and fewer extraction locations. We estimate that the Deferred-Action Alternative would take about 230 years to achieve remediation goals, and remediation may not begin for 200 years. Each treatment option, combined with the same remedial alternative, would require the same length of time to achieve the remediation goals.

Implementability. Each of the remedial alternatives and technology options is technically and administratively feasible and supported by available services, materials, and skilled labor. An advantage of the UV/oxidation technology over the GAC technology is that regeneration of the spent carbon is unnecessary. The air-stripping-based and UV/oxidation-based technologies generate substantially less spent carbon than the GAC system for water treatment. UV/oxidation and GAC technologies also have minimal visual impact compared to air-stripping towers.

Cost. The present worth of Remedial Alternative No. 1 (the preferred alternative) is estimated to be \$103 million, assuming 50 years of operation. The present worth for 90 years of

operation for Remedial Alternative No. 2 is \$99 million. The present worth for Remedial Alternative No. 3 is \$87 million, assuming air stripping is the treatment option used. If Remedial Alternative No. 3 consisted only of monitoring ground water for 100 years, the present worth would be \$12 million.

State Acceptance. State agency acceptance will be addressed following the public comment period on this PRAP.

Community Acceptance. Preliminary input received at Community Work Group meetings indicates there is some community preference for UV/oxidation-based remediation technology because it destroys the contaminants onsite and does not involve transferring them to GAC, which requires transport and regeneration. Community acceptance will be formally addressed after the public meeting on November 6, 1991, and the close of the public comment period on November 18, 1991.

6.3.2. Unsaturated Zone

The remedial alternatives for the unsaturated zone are described below and compared in Table 7 in terms of the EPA evaluation criteria.

Overall Protection of Human Health and the Environment. Remedial Alternative No. 1, using any of the treatment options, is protective of human health and the environment and creates minimal health risks. The Deferred-Action Alternative has some impact on the subsurface above the water table as contaminants migrate naturally. Estimates indicate natural processes would reduce the concentrations to below MCLs in 90 to 140 years (Isherwood *et al.*, 1990, Appendix G).

Compliance with ARARs. Remedial Alternative No. 1, using any of the treatment options, is designed to achieve ARARs. The Deferred-Action Alternative may allow contaminants to reach the ground water in concentrations exceeding MCLs in a few isolated places (i.e., Gasoline Spill and Building 518 Areas, and perhaps the East Taxi Strip Area).

Long-Term Effectiveness and Permanence. Both of the alternatives are effective in the long run and reduce health risks permanently by the ultimate destruction of the contaminants.

Reduction in Toxicity, Mobility, and Volume. Remedial Alternative No. 1 results in the complete breakdown of compounds to harmless substances, thereby permanently reducing toxicity, mobility, and volume. Remedial Alternative No. 2 (deferred action) allows VOCs and FHCs to continue to migrate through the unsaturated zone to the ground water. VOCs and FHCs would then be extracted and treated in the ground water at the nearest treatment facility.

Short-Term Effectiveness. Both alternatives would expose workers, the public, and the environment to negligible impacts during installation and operation. Achieving the remediation objectives is estimated to require 10 years for the preferred alternative, and 90 years for the Deferred-Action Alternative (Isherwood *et al.*, 1990).

Implementability. Both alternatives are technically and administratively feasible and supported by available services, materials, and skilled labor.

Cost. Present worth cost for 10 years of operation for the preferred alternative is \$1.1 million. The preferred alternative utilizes the most cost effective treatment option available for both VOCs and FHCs. The present worth of the Deferred-Action Alternative is \$850,000.

State and Community Acceptance. Both State and community acceptance will be formally addressed after the public meeting on November 6, 1991, and the public comment period on November 18, 1991.

6.4. Summary of Preferred Alternatives

The Feasibility Study evaluated many potential remedies for the LLNL site. Those remedies are divided into two general groups, according to whether the chemical contaminants are in ground water or in unsaturated sediment. Three alternatives were evaluated for the ground water plume, and two remedies were evaluated for the unsaturated zone.

The preferred alternative for ground water is Remedial Alternative No. 1, which involves:

- Immediately pumping water at 18 initial locations within the ground water plume. Water would be pumped from one or more wells at each of these locations using existing monitor and extraction wells, along with new extraction wells. The well locations would be chosen to prevent any VOCs from escaping from the area in concentrations above their MCLs. To enable more rapid remediation, wells would also be placed in all areas where VOC or FHC concentrations in ground water exceed 100 ppb.
- Construction of seven onsite facilities (A to G) to treat the extracted ground water. Each treatment system would be designed to treat a somewhat different combination of compounds in the associated extraction wells.
- Treatment Facilities A, B, E, and F would use UV/oxidation-based remediation technology to treat VOCs. Treatment Facilities C, D, and G would use air-stripping-based technology, which is more effective on the higher concentrations of specific compounds in the area of those facilities (chloroform, carbon tetrachloride, Freon 113, and 1,1,1-TCA).

The preferred alternative for the unsaturated zone is Remedial Alternative No. 1. This alternative involves using a process called vacuum-induced venting to extract the contaminants in vapor form from the unsaturated sediments, and treating the vapors by catalytic oxidation.

LLNL evaluated these alternatives according to specified U.S. EPA criteria for assessing remedial technologies at Superfund sites. The two most important criteria are the ability to provide adequate public health and environmental protection, and compliance with State, Federal, and local requirements (ARARs). The chosen alternatives also should be technically feasible to implement; be cost-effective; provide for long- and short-term effectiveness and permanence; reduce the toxicity, mobility, and volume of the contaminants; and be acceptable to the regulatory agencies and the community. Although comments from the community and regulatory agencies have influenced the design and selection of alternatives through the Superfund planning process to date, their support for the alternatives will again be taken into account formally after public comment is received on this PRAP.

Based on the Remedial Investigation and Feasibility Study analyses, DOE, LLNL, U.S. EPA, DTSC, and the RWQCB, believe that the preferred alternatives for the ground water and unsaturated zone contaminants fully satisfy the evaluation criteria. Although more expensive in the short-run, the preferred ground water and vadose zone alternatives satisfy the State ARAR for nondegradation of the ground water, reduce the mobility of the contaminants, provide a permanent solution, utilize alternative treatment technologies to the maximum extent practicable, and would achieve cleanup faster than the other alternatives.

6.5. Post Record of Decision Activities

After the Record of Decision (Fig. 2), the engineering design, schedule, and other details of implementing the conceptual approaches to cleanup presented in this report will be described in the Remedial Action Implementation Plan and the Remedial Design Report. These reports will include details regarding the implementation and monitoring of the cleanup over time. LLNL and DOE will report on the progress of the cleanup in monthly reports which will be available to the public. If desired by the local community, LLNL will continue to support a Community Work Group to enable public input as remediation proceeds. The Record of Decision will also include formal reviews of the cleanup at 5-year intervals until the cleanup is complete.

LLNL will continue to investigate potential sources of soil and ground water contamination until all known potential sources are investigated. Potential sources requiring remediation that may be discovered in the future will be cleaned up with regulatory oversight.

7. Community Participation

We strongly encourage all interested persons to provide input regarding the selection of remedial actions for the LLNL site. Interested persons should provide written comments on this draft report to any one of the individuals listed below. The formal comment period on the PRAP will extend from October 18 to November 18, 1991. LLNL will hold a public meeting on the PRAP on:

Wednesday, November 6, 1991
7 p.m. to 10 p.m.
at the Livermore High School Student Union Building
(the round building behind the school)
600 Maple Street
Livermore, California

The purpose of the meeting will be to present the PRAP and the preferred cleanup alternatives. Both LLNL and regulatory agency staff will be available for an open discussion and question-and-answer session. Time also will be available to receive your verbal public comments.

Project documents are available for review from the information repositories, which are located at:

LLNL Visitors Center
(enter from Greenville Road)
Livermore, California 94551
Open 9 a.m. to 4:30 p.m.,
Monday through Friday;
12 noon to 5 p.m., Saturday
(510) 423-9797

Livermore Public Library
1000 South Livermore Avenue
Livermore, California
Open 10 a.m. to 9 p.m.,
Monday through Thursday;
10 a.m. to 5 p.m., Friday and Saturday;
1 p.m. to 4 p.m., Sunday
(510) 373-5500

Comments on this Proposed Remedial Action Plan may be sent to, and additional information may be obtained from:

John Ziagos
Acting Ground Water Project Leader
Environmental Restoration Division
LLNL (L-528), P. O. Box 808
Livermore, California 94551
(510) 422-5479
8 a.m. to 5 p.m., Monday–Friday

Pat Post
Community Relations Coordinator
Environmental Protection Department
LLNL (L-192), P. O. Box 808
Livermore, California 94551
(510) 423-4255
8 a.m. to 5 p.m., Monday–Friday

John Chesnutt
Remedial Project Manager
U.S. Environmental Protection Agency
Hawthorne Street, H-7-5
San Francisco, California 94105
(415) 744-2387
9 a.m. to 5 p.m., Monday–Friday
(Messages 24 hr/day)

Michelle Rembaum
Project Manager
California Environmental Protection
Agency, Department of
Toxic Substances Control
700 Heinz Avenue, 2nd Floor, Bldg. F
Berkeley, California 94710
(510) 540-3847
9 a.m. to 5 p.m., Monday–Friday

Rico Duazo
Project Officer
California Regional Water Quality
Control Board
2101 Webster Street, 4th Floor
Oakland, California 94610
(510) 464-0837
8 a.m. through 5 p.m., Tuesday–Friday

8. Glossary

Administrative Record (AR)	A publicly accessible collection of all significant information gathered regarding a CERCLA decision, including public comments, used to arrive at a Record of Decision and selection of a remedy.
Air stripping (AS)	A well-established process of physical removal (stripping) of volatile compounds from water to air.
Alameda County Flood Control and Water Conservation District–Zone 7 (Zone 7)	The water management agency for the Livermore-Amador Valley responsible for water treatment and distribution.
Applicable or Relevant and Appropriate Requirements (ARARs)	Remediation standards, standards of control (emission standards), and other substantive environmental protection concentration limits, criteria, or limitations for a specific medium specified by Federal or State law.
Aquifer	A saturated (water-bearing) layer of rock or unconsolidated sediment below the ground surface that can supply usable quantities of water to wells or springs.
Aromatic hydrocarbons	Hydrocarbons such as benzene and xylene, which are components of gasoline.
Arroyo	Water-carved gully, dry wash, or ravine, generally in arid or semiarid regions.
Baseline Public Health Assessment (BPHA)	An assessment of the risks, in the absence of remediation, to public health and the environment from materials introduced into the environment by man.
Bay Area Air Quality Management District (BAAQMD)	The local agency responsible for regulating stationary air emission sources in the San Francisco Bay Area.
Best-estimate	An estimate deemed to be the most likely occurrence.
Bioremediation	Use of microorganisms that metabolize specific compounds to transform them to less or nontoxic substances.

California Environmental Protection Agency, Department of Toxic Substances Control (DTSC)	California agency that regulates hazardous waste management and remedial actions.
Catalytic oxidation	A process in which air containing organic vapors is heated to a temperature sufficient to completely oxidize the compounds using a catalyst that facilitates the oxidation process.
Community Work Group	A key element of the LLNL Community Relations Program; interested community members meet on a regular basis with Ground Water Project staff.
Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)	This Federal Law, passed in 1980, is also known as Superfund. It authorizes the Federal Government to respond directly to releases of hazardous substances that may endanger health or the environment.
Deferred-Action Alternatives	As defined at LLNL, remedial actions that may be implemented in the future while contaminants are undergoing natural processes of change or are migrating to other points of remediation.
Department of Energy (DOE)	The Federal agency that owns LLNL and has an agreement with the University of California whereby the University administers the day-to-day operations of the Laboratory. DOE is the Federal administrative agency charged with energy and certain weapons research.
Dilution	Reduction in concentration of a substance in a vapor or liquid by the addition of more host liquid or vapor.
Downgradient direction	The direction of the ground water flow.
Effluent	A fluid (liquid or gaseous) discharge, usually after treatment.
Feasibility Study (FS)	A study based on the Remedial Investigation to evaluate and develop remedial action alternatives to cleanup hazardous materials in the environment.
Fuel hydrocarbons (FHCs)	Components of fuel including aromatic hydrocarbons and ethylene dibromide. At LLNL, refers primarily to components of regular leaded gasoline.

Gasoline Spill Area	Area in southern LLNL where about 17,000 gallons of gasoline leaked out of an underground tank prior to 1979. The area covers about an acre.
Granular-activated carbon (GAC)	A well-established technology generally effective for removing high molecular weight compounds, chlorinated solvents, petroleum hydrocarbons, and some inorganic ions from fluid.
Half-life	The time it takes for one-half of the mass of a substance to decay naturally into another substance.
Hazard index (HI)	A measure of the estimated maximum chronic daily intake of a chemical or group of chemicals that is used to determine whether adverse health effects, other than cancer, might result.
Hazardous waste	Materials defined and regulated by the EPA in the Resource Conservation and Recovery Act (RCRA).
Health risk	(See risk assessment.)
Health conservative	A set of assumptions that are conservative from a health risk perspective.
Hydraulic gradient	In an aquifer, at a given point, the change of total head (water-level elevation) per unit distance in a particular direction.
Hydrology	The science of dealing with the properties, distribution, and circulation of natural water systems.
Inorganic compounds	Compounds that either do not contain carbon or do not contain hydrogen along with carbon.
Ion	An electrically charged atom or molecule.
Ion exchange	A proven technology for removing metal ions from water.
Isoconcentration contour	A line on a map connecting points of equal chemical concentration.
Maximum additional cancer risk	The maximum risk of developing cancer in addition to the one in four risk from natural causes.

Maximum concentration or contaminant limit (MCL)	The maximum concentration of a substance permitted by Federal or State statute or regulation (by EPA or DHS) in drinking water.
Metabolic destruction	(See bioremediation.)
National Pollutant Discharge Elimination System (NPDES)	Under the Clean Water Act, this Federal regulation requires permits and monitoring for discharges into surface waterways.
National Priorities List (NPL)	EPA's list of the top-priority hazardous waste sites in the country that are subject to the Superfund program.
Nine EPA criteria for detailed evaluation	Criteria developed by the EPA to evaluate remediation alternatives.
Oxidation, oxidize	A chemical process in which a substance is combined with oxygen or the positive charge is increased.
Present worth	A means of calculating equivalent values for expenditures that occur in different years. A typical application of this procedure, called discounting, is estimating the cost or return on investment of projects that begin in different years, have different duration periods, and have different year-by-year costs. The present worth is calculated by incorporating the influence of certain factors into future expenditures. These factors include the time value of money, inflation, profit (if any), and the cost of borrowing money. In the FS and PRAP, we have considered only the time value of money, which is a measure of the penalty paid for investing funds in one project as opposed to investing them in many uses.
Primary treatment	The first and usually most important treatment of water or vapor, during which hazardous substances are removed or destroyed.
Proposed Remedial Action Plan (PRAP)	A plan describing the preferred set of remedial alternatives for a site, selected from all the alternatives considered.
Recharge basin	The two-celled pond south of East Avenue used to return treated water back to the subsurface by infiltration.

Record of Decision (ROD)	The public record of the selection of a remediation alternative and a documentation of the remedial action plan for its implementation.
Remedial (action) objectives	The goal of the remediation stated as an objective designed to meet the ARARs; commonly, these goals are stated in terms of concentration limits in treated water effluent or concentration of substances remaining in ground water or soil.
Remedial Investigation (RI)	An investigation conducted to fully assess the nature and extent of the release, or threat of release, of hazardous substances, pollutants, or contaminants, and to gather necessary data to support the associated feasibility study.
Remediation	Removing compounds introduced to the environment by man and restoring the environment to or near original or background concentrations.
Remediation technologies	Technologies for destroying or removing substances from the environment.
Resource Conservation and Recovery Act (RCRA)	An amendment to the first Federal solid waste legislation, the Solid Waste Disposal Act of 1965. It requires "cradle to grave" tracking and management of hazardous materials.
Risk assessment	The use of established methods to estimate the risks posed by an activity such as hazardous waste treatment.
San Francisco Bay Regional Water Quality Control Board (RWQCB)	The regional agency responsible for water quality standards and the enforcement of State water quality laws within its jurisdiction.
Saturated zone	A subsurface zone below which all pore space is filled with water.
Screened zone	In a well, the section that contains the screen, or perforated pipe, that allows water to enter the well.
Secondary treatment	Treatment of water or vapor following primary treatment to remove compounds not removed or destroyed by the primary treatment process.

State Water Resources Control Board (SWRCB)	The State agency that develops and adopts Statewide water quality plans and policies.
Superfund	The common name used for the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).
Superfund Amendments and Reauthorization Act (SARA)	This Federal Law, passed in 1986, modifies and reauthorizes CERCLA.
Surficial soils	Unconsolidated surficial material up to a few feet deep.
Thermal oxidation	A process of chemically transforming substances in vapor by heating the vapor to temperatures sufficient to oxidize the substances.
Total undiscounted costs	The sum of the annual costs, in 1990 dollars, without discounting.
Units of measure	<p>Ci (Curie). A unit of measurement of radioactivity, defined as the amount of radionuclide in which the decay rate is 2.22×10^{12} disintegrations per minute (3.7×10^{10} disintegrations per second), which is approximately equal to the decay rate of one gram of pure radium. One picocurie (pCi) is one one-trillionth (1×10^{-12}) Ci.</p> <p>gpm (gallons per minute). A measure of flow of a liquid.</p> <p>millirem. One one-thousandth of a rem. The unit used to express human biological doses that result from exposure to one or more types of ionizing radiation. A chest X-ray results in a typical exposure of about 20 millirem.</p> <p>ppb (parts per billion). The concentration of a substance in its surrounding medium. For example, one billion grams of water containing one gram of salt has a salt concentration of one part per billion.</p> <p>ppm (parts per million). A unit of measure for the concentration of a substance in its surrounding medium. For example, one million grams of water containing one gram of salt has a salt concentration of one part per million.</p>

Unsaturated zone	That portion of the subsurface above the water table in which the pores spaces are only partially filled with water.
U.S. Environmental Protection Agency (U.S EPA)	The U.S. Federal regulatory agency responsible for enforcing Federal environmental laws.
UV/oxidation	A process of chemically transforming substances in water by introducing a strong oxidizing agent such as hydrogen peroxide, the action of which is enhanced by the presence of ultraviolet light.
Vacuum-induced venting	Withdrawing vapor from the unsaturated zone by using a pump at the surface of a well with specially designed casing to create a vacuum that vents or extracts the vapor, which can then be treated.
Volatile organic compound (VOC)	Liquid organic compounds that have a tendency to spontaneously evaporate. Used at LLNL to incorporate a variety of chlorinated solvents.
Water table	The level to which a shallow well would fill with water.
Chemicals:	
1,1-dichloroethane (1,1-DCA)	Organic compound found in antiknock gasoline, paint, and varnish and finish remover.
1,1-dichloroethylene (1,1-DCE)	Organic compound with similar uses to 1,1-DCA.
1,2-dichloroethane (1,2-DCA)	Organic compound with similar uses to 1,1-DCA.
1,2-dichloroethylene (1,2-DCE)	Organic compound with similar uses to 1,1-DCA.
Benzene	An aromatic hydrocarbon and a component of gasoline.
Carbon tetrachloride	Organic compound used as a cleaning agent.
Chloroform	Organic compound used as a cleaning agent; also a byproduct of chlorinating drinking water.
Chromium	A metallic element that has been used at LLNL as a cooling tower corrosion inhibitor.

Ethylbenzene	An aromatic hydrocarbon and a component of gasoline.
Ethylene dibromide	Organic compound used in medicine as a solvent in organic synthesis and as an antiknock agent in gasoline.
Lead	A metallic element used in organic form as an antiknock agent in gasoline.
Perchloroethylene (PCE)	Also known as tetrachloroethylene. Organic compound widely used as a cleaner or solvent.
Toluene	An aromatic hydrocarbon and a component of gasoline.
Trichloroethylene (TCE)	Organic compound widely used as an industrial degreaser, a dry cleaning agent, and a fumigant.
Tritium	A hydrogen isotope with one proton and two neutrons in the nucleus. It emits a low-energy beta particle. Tritium has been used at LLNL in the weapons program and in the development of laser and magnetic fusion energy, new rocket fuel, and biomedical research.
Xylene	An aromatic hydrocarbon and a component of gasoline.

9. References

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Appendix A. Programmatic Cost Information

Programmatic and other costs of the remedial alternatives were included in the PRAP to more completely describe the total comparative cost of remediation. During preparation of the PRAP, the conceptual design of three ground water and two unsaturated zone remedial alternatives for the LLNL Livermore site were developed in more detail than in the FS (Isherwood *et al.*, 1990, Sections 3 and 4).

During preparation of the PRAP, we were able to more accurately estimate the costs of the remedial alternatives, including specific numbers of treatment facilities and their associated technologies. We also were better able to estimate the time required to achieve ARARs and costs for operation and maintenance (O&M) of the remedial alternatives. Additional new extraction wells will also probably be required to allow us to respond to changing conditions as cleanup progresses. Consequently, the cost of additional piezometers and extraction wells was added to provide more data for management of the continued remediation. We added the cost of recharge wells and infiltration trenches because an optimized pump and treat system will use the treated water to expedite cleanup.

The programmatic costs were estimated by evaluating current LLNL Environmental Restoration Division expenditures in major components and assigning costs to the remediation project components. These components and estimated annual expenditures for the ground water remediation are shown in Table A-1.

Table A-1. Annual programmatic costs assigned to ground water remediation (1990 dollars).

Program component	Remedial Alternatives			
	No. 1	No. 2	No. 3a	No. 3b
	Millions of dollars (1990)			
Plume monitoring: chemistry, hydrology	1.50	1.50	0.50	0.25
Reservoir engineering: data mgt., operating decisions, modeling	0.75	0.75	0.00	0.00
Administration/QA	0.75	0.75	0.50	0.25
Reporting	0.75	0.75	0.50	0.10
Source investigations	0.25	0.25	0.25	0.00
Total annual programmatic costs	4.00	4.00	1.75	0.6

These annual expenditures are calculated for the operating times for each ground water remedial alternative using the discounting procedure described in Section 5.2 (Table A-2).

Table A-2. Present worth values of annual programmatic administrative costs (millions of 1990 dollars).

Period	Discount factor	50-year operation ^a	90-year operation ^a	100 years of monitoring ^b	30-year operation in 200 years ^b
Through year 30	15.37	61			
Through year 50	18.25	73			
Through year 90	19.75		79		
Through year 100	19.85			12	
Through year 230	20.0				87

^a Discount rate is 5%, suggested by EPA (1989b), and is intended to be net of inflation, profit, or the cost of money; in other words, it is intended to cover the time value of money only.

^b Thirty years of operating and maintenance expense discounted at 5% (years 2190 to 2220) for consistency with the discounting procedure of other alternatives. The 30-year discounted value (year 2190 dollars) is discounted from years 1990 to 2190 using 2%, which represents the long-term value of money.

The costs given in Section 5 of this report include common elements (see Table 4) that consist of management, supervision, and additional facilities associated with the ground water remediation project as a whole. These costs, which were not included in the analyses in the FS, do not substantially alter the relative costs among the sitewide remedial alternatives, although they are significant in magnitude. Program operation costs are included for ground water remediation only because the major remediation effort will be for ground water.

Appendix B. Rationale for Preferring Catalytic Oxidation for Treatment of Fuel Hydrocarbons and VOCs in Vapor

To remediate the saturated zone in the Gasoline Spill Area at LLNL, a combined dewatering/vapor extraction approach is planned. The saturated zone in the Gasoline Spill Area contains low concentrations of the halogenated compounds trichloroethylene (TCE), 1,2-dichloroethane (1,2-DCA), and ethylene dibromide (EDB), in addition to the fuel hydrocarbons. The thermal oxidizer in use for the Gasoline Spill Pilot Study effectively treats the fuel vapor withdrawn from the unsaturated zone. However, thermal oxidation of benzene in the presence of TCE and 1,2-DCA could potentially produce dioxin. The catalyst HDC has recently been developed by Allied Signal, Inc. This catalyst is apparently not "poisoned" (rendered ineffective) by the VOCs, and it helps destroy both VOCs and fuel hydrocarbons. Use of this new catalyst will destroy dioxin that may be produced by oxidation of aromatic and halogenated compounds.

Analyses of sediment from the Gasoline Spill Area indicate that halogenated compounds are not present in the unsaturated zone. Thus, there is no potential for the production of dioxin when treating vapors from the unsaturated zone.

The oxidation of the halogenated compounds will also produce minor amounts of hydrogen chloride (HCl) and hydrogen bromide (HBr), which can be removed by a caustic scrubber. The lower temperature of the catalytic oxidizer (700°F versus 1,800°F for the thermal oxidizer) makes caustic scrubbing much easier. In addition, one-third of the supplemental fuel is required for the catalytic oxidizer compared to the thermal oxidizer.

Use of a catalytic oxidizer provides the flexibility to treat both fuel hydrocarbons and VOCs together and substantially reduces the potential for producing dioxin. These advantages of catalytic oxidation make it the preferred treatment for vapors withdrawn from the unsaturated zone at LLNL.